

## THE POTENTIALS OF ELECTROMAGNETIC RADIATION IN AGRICULTURE

Let us harness the sun. There are hungry people in the world; our crop plants use only a little of the sun's energy in photosynthesis. Why not more? Why not? Corn plants from seed planted parallel to the row extend their leaves into interrow spaces, there exposing a greater surface to sunlight. The geometry of crop plantings and plant growth, the movement of air, maintaining CO<sub>2</sub> concentration about the plant, may affect efficiency. The lower leaves of a plant may receive no direct sunlight. Lemon (1963) reported that only 17 percent of net radiation reached the soil in a dense corn crop.

Much of the sunlight energy is used for evapotranspiration from soil and plant. This helps keep the plant cool on hot days? But in the noonday sun many plant stomata close, transpiration is checked. But what of the effect on plant temperature?

In any case, agriculture is a lavish user of water. Water is often scarce during part of the growing season. Optimal use of water for plant growth depends on more effective use of sun's energy. Agricultural engineers are essential members of research teams, whether the research is conducted in growth chambers or in the field. Without their know-how the presumably controlled temperature, light, temperature, humidity and air movement and CO<sub>2</sub> concentration in the growth chamber may become irregular. Adequacy of field observations may not be obtained.

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Talk by Administrator T. C. Byerly, Cooperative State Research Service, U. S. Department of Agriculture, given before the Conference on Electromagnetic Radiation in Agriculture, Roanoke, Virginia, October 18, 1965.

THE EFFECTS OF ELECTROMAGNETIC RADIATION ON PLANTS

It is well known that plants are affected by electromagnetic radiation. The effects of such radiation on plants have been studied for many years. The results of these studies have been used to develop methods for controlling plant growth. The following are some of the effects of electromagnetic radiation on plants:

1. **Stimulation of Growth:** Electromagnetic radiation can stimulate plant growth. This is especially true in the case of low frequency radiation. The stimulation of growth by electromagnetic radiation has been used to develop methods for increasing the yield of crops.

2. **Inhibition of Growth:** Electromagnetic radiation can also inhibit plant growth. This is especially true in the case of high frequency radiation. The inhibition of growth by electromagnetic radiation has been used to develop methods for controlling the growth of weeds.

3. **Changes in Leaf Area:** Electromagnetic radiation can cause changes in the area of plant leaves. This is especially true in the case of low frequency radiation. The changes in leaf area caused by electromagnetic radiation have been used to develop methods for controlling the growth of crops.

4. **Changes in Flowering Time:** Electromagnetic radiation can cause changes in the time at which plants flower. This is especially true in the case of low frequency radiation. The changes in flowering time caused by electromagnetic radiation have been used to develop methods for controlling the growth of crops.

5. **Changes in Fruit Size:** Electromagnetic radiation can cause changes in the size of plant fruits. This is especially true in the case of low frequency radiation. The changes in fruit size caused by electromagnetic radiation have been used to develop methods for controlling the growth of crops.

6. **Changes in Plant Color:** Electromagnetic radiation can cause changes in the color of plant leaves. This is especially true in the case of low frequency radiation. The changes in plant color caused by electromagnetic radiation have been used to develop methods for controlling the growth of crops.

7. **Changes in Plant Height:** Electromagnetic radiation can cause changes in the height of plants. This is especially true in the case of low frequency radiation. The changes in plant height caused by electromagnetic radiation have been used to develop methods for controlling the growth of crops.

8. **Changes in Plant Weight:** Electromagnetic radiation can cause changes in the weight of plants. This is especially true in the case of low frequency radiation. The changes in plant weight caused by electromagnetic radiation have been used to develop methods for controlling the growth of crops.

9. **Changes in Plant Quality:** Electromagnetic radiation can cause changes in the quality of plant products. This is especially true in the case of low frequency radiation. The changes in plant quality caused by electromagnetic radiation have been used to develop methods for controlling the growth of crops.

10. **Changes in Plant Quantity:** Electromagnetic radiation can cause changes in the quantity of plant products. This is especially true in the case of low frequency radiation. The changes in plant quantity caused by electromagnetic radiation have been used to develop methods for controlling the growth of crops.



Dr. Hesketh (1965) at the University of Arizona has rated plants according to the amounts of  $\text{CaO}_{2A}$  assimilated under like environmental conditions. Corn, sorghum, tropical grasses generally, and pigweed had the highest rate of photosynthesis, using 50 to 70 mg  $\text{CO}_2$  per dm per hour. Sunflower and cotton used 40 to 50 mg in terms of the same leaf surface. Most crop plants used  $\text{CO}_2$  at a 20 to 40 mg per hour rate, but some, including tomatoes, soybeans and beans, were in the lower portion of this range. Northern deciduous tree species, citrus, grapes and house plants had a still lower rate of 10 to 20 mg per hour.

Generally, plants with few or no stomata on the upper leaf surface and those of few stomata anywhere showed a low rate of  $\text{CO}_2$  use. Shade-grown cotton and sunflower used  $\text{CO}_2$  at a lower rate than sun grown.

A common usage of plant geometry in maximum exposure of leaf surface to sunlight is skip-row planting, widely practiced by cotton growers. By planting two rows, then skipping a row, each row is a border row and yield per plant is increased.

Increased grape yields obtained by users of Geneva "double curtain" grape trellis is partly due to better leaf exposure. Alternate plants in the same row are trained on widely separated wires at about 6-foot height on arms from trellis posts (Shaulis, 1965).

Light energy is used in photosynthesis by green plants and some microbes to accomplish the synthesis of living substance from nitrogen, oxygen, carbon, hydrogen, and a few other elements. Research during the past few years has revealed pathways, compounds, processes by which photosynthesis is accomplished. With this and other new knowledge, chemists, physicists and biologists may be able to accomplish analogous synthesis without the use of biological organisms.





Green plants use water as a photoreductant in photosynthesis.

Chlorophyll is used to absorb light. Absorbed light energy is transferred to chemical energy, which the plant can use (Whatley and Losada, 1964).

Melvin Calvin of the University of California at Berkeley was awarded a Nobel prize for his contribution to knowledge of photosynthetic process.

True Hinton and his coauthors, Wiant and Brown (1958) stated a dictum which I shall state now and will state twice again before I finish. It is:

"If electrons move, there is an electric current, and consequently an electromagnetic field."

Among the many sophisticated biophysical methods used in the study of photosynthesis is that of electron spin resonance (Zavorsky 1945; Commoner et al, 1954), with its application to plant physiology. The apparatus used is called an electron spin resonance spectrophotometer. According to Blois et al. (1964), it is sensitive enough to detect and give a basis for estimating unpaired electron concentration in living material under nearly normal physiological conditions. Its use has identified two sets of light related signals from chloroplast systems--one when illuminated, and another when light is removed. Blois et al. (loc. cit.) state that "The most significant contribution of this technique has probably been the unequivocal confirmation of Michaelis's prediction that biological oxidations are one electron transfers."

Electron spin resonance is measurable under conditions of paramagnetism, which occurs when an atom or molecule has one or more impaired electrons. There is life, we live, because there are unpaired, excited electrons. Too many of them and what we call excitement would hardly describe the disturbed condition which would result.





While photosynthesis is a major process in utilization and storage of electromagnetic energy from the sun, in general there must be a green plant in which photosynthesis can take place.

The reproductive and growth cycle of green plants is largely light dependent. The influence of day length on time of flowering was established by Garner and Allard about 1920. Flint and McAlister (1935) found that germination of lettuce seed was by red radiation and suppressed by radiation near the red limit of the visible spectrum. Further researches have demonstrated that stem elongation, leaf movement and expansion, seed germination, anthocyanin production, plastid formation and bud dormancy are all light dependent.

Parker et al. (1946) demonstrated that light in the near red (660 mμ) and far red (730 mμ) is involved. Further researches have established the identity of a blue pigment, phytochrome, which undergoes a reversible photo-reaction in response to near and far red light exposure of appropriate time and intensity (Hendricks, 1964). Application of the information on plant photoperiodism is widely used to regulate growth habit and time of flowering by growers of flowers and ornamentals. Geneticists have selectively bred corn and soybeans adapted to the day lengths of various latitudes. Surely agricultural engineers will find wider opportunities for the use of this knowledge. One rapidly growing application is the arrangement for lighting of patio and parlor gardens according to the assortment of ornamentals used. Apparently, blue light may also control some photoperiodic reactions. A preliminary report by Raymond Lukens (1965) of the Connecticut Agricultural Experiment Station indicates that tomato early blight fungus may be prevented from sporulating by interrupting the night with blue light.





Plants may emit light, too. According to Chase (1964), luminescence in green plants was first demonstrated by Strehler and Arnold (1951), who made some beautiful quantitative measurements on the relatively dim light emission of three algae and two higher plants.

Hastings (1964) reported that the action spectrum for phase shift in *Gonyaulax* has maxima at 475 mu and 650 mu. Light at the red maxima is less effective than at the blue. Action spectrum corresponds roughly to absorption spectrum of chlorophyll c, but a causal relation not established. Hastings found no evidence of a reversal of the red effect (650 mu) by far red light (730 mu), and far red light alone was ineffective in causing a phase shift.

#### Light traps.

Light traps built to meet the determined responses of pest insects to light of specific wave lengths from U V to infrared seem to me to have a growing place in insect control. Combined with lures and baits containing chemosterilants, their effectiveness may be increased greatly.

Callahan (1965) has developed the hypothesis that corn earworm moths are attracted for mating and perhaps to host plants by high-frequency microwave electromagnetic radiation somewhere in that portion of the spectrum between extremely high-frequency (EHF) and far infrared (FIR), or intermediate infrared (IIR) radiation of  $10^5$  to  $10^7$  megacycles. This is an area of the spectrum for which sufficient instrumentation is lacking.

Work in England (Laithwaite, 1960) with the rusty tussock moth (vapourer), *Orgyia antiqua*, gave indirect evidence that this species is attracted to the opposite sex by high-frequency radiation. Laithwaite believes that the pectinated antennae of the male serve as defraction

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emission of certain algae and higher plants.

Robert Hargrave (1964) reported that the action spectrum for trans shift in

Euglenella has maxima at 415 mμ and 680 mμ. Light at the red extreme is less

effective than at the blue. Action spectrum corresponds roughly to absorp-

tion spectrum of chlorophyll a, but a causal relation not established.

Hargrave found no evidence of a reversal of the red effect (680 mμ) by far

red light (730 mμ), and far red light alone was ineffective in causing a

phase shift.

#### Light trace.

Light traps built to test the determined responses of pest insects

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a growing place in insect control. Combined with light and bait contain-

ing pheromones, their effectiveness may be increased greatly.

Callahan (1962) has developed the hypothesis that even narrow wings

are attracted for mating and feeding to host plants by high-frequency

ultrasonic electromagnetic radiation emanating in that portion of the

spectrum between extremely high-frequency (EHF) and far infrared (FIR), or

intermediate infrared (IR) radiation of 10<sup>10</sup> to 10<sup>12</sup> megacycles. This is

an area of the spectrum for which scientific instrumentation is lacking.

Work in England (Lalithorpe, 1960) with the newly common moth

(*Agrotis*), *Agrotis* and *Agrotis*, gave indirect evidence that this species is

attracted to the spectrum of high-frequency radiation. Lethal

effects that the pest insects suffered at the end of the spectrum

of the spectrum of high-frequency radiation.



grids for reception of (presumed) radiation from the female (wingless) in this species. It seems highly probable that if the moth antennae were to serve as defraction grids, or even tuned dipoles for EHF reception, a prerequisite for microwave electromagnetic transmission and reception would be in-flight stability of the antennal sensory unit. Furthermore, if the sensory pits of the noctuid antennae are to be considered as possible dielectric wave guides or resonators to infrared, the presence of in-flight antennal stability would be a necessity.

Callahan tested antennal in-flight stability by a series of ingenious tests and demonstrated such stability.

Further research was presented by Callahan at a AAAS symposium at Montreal in 1964. He reported that:

1. Newly emerged moths wander randomly at considerable heights.
2. These moths are attracted by IR emission and reflection into host plants.
3. The efficiency of plant or moth attraction is dependent on prevailing weather parameters which affect the IR transmission.
4. Moths near each other, either because a plant or a pocket having optimum thermal patterns attract them, vibrate their wings and send out FIR signals which are identified by the IR eye or certain tuned spines of the antennae of the opposite sex.

Host location and insect communication depend upon the detection of frequencies in the 1 to 18  $\mu$  spectrum. Frequency transmissions in the 9  $\mu$  region have been received, amplified, and recorded on an oscilloscope from moths in the families Noctuidae, Sphingidae, and Lasiocampidae. In addition, various species of Noctuidae have been attracted to a black body emitting in the 9  $\mu$  region in a totally dark room.

grids for reception of (transmitted) radiation from the female (wingless) in this species. It seems highly probable that if the antennae were to serve as detection grids, or even tuned dipoles for EMP reception, a specialized for microwave electromagnetic transmission and reception would be in-flight stability of the antennal sensory unit. Furthermore, if the sensory unit of the antennal apparatus are to be considered as possible electrostatic wave guides or resonators in flight, the presence of in-flight antennal stability would be a necessity.

Calishan tested antennal in-flight stability by a series of ingenious tests and demonstrated such stability. Further research was presented by Calishan at a AAS symposium at Montreal in 1964. He reported that:

1. Newly emerged male wander randomly at considerable heights.
2. These males are attracted by IR emission and reflection from host plants.
3. The efficiency of plant or moth attraction is dependent on prevailing weather parameters which affect the IR transmission.
4. Males near each other, either because a plant or a host plant having optimum thermal pattern attract them, attract their wings and send out EIR signals which are identified by the IR eye or certain tuned apices of the antennae of the opposite sex.

Host location and sensory communication depend upon the detection of frequencies in the 1 to 100 spectrum. Frequency transmission in the 1 to 100 region have been received, amplified, and recorded on an oscilloscope from moths in the families Noctuidae, Spodoptera, and Tortricidae. In addition, various species of Noctuidae have been attracted to a black body emitting in the 10 region in a totally dark room.



The insect ocellus is a cup-shaped eye equipped with a lens and a pigment cup backing the receptors. The ocelli have never been considered as image-forming organs. They do, however, direct important behavior, including (according to Harker, 1950) diurnal activity rhythms and (according to Wellington, 1953) phototaxis.

The demonstration by von Frisch of the significance of polarized light in the behavior of bees was followed by work on other species. Kennedy (1964) stated that Kuwabara and Naka (1959) and Burkhardt and Wendler (1960) independently succeeded in penetrating the retinula cells of dipteran eyes with microelectrodes. Some recorded units showed polarization sensitivity; in the Burkhardt and Wendler experiment, a  $90^{\circ}$  difference in plane of polarization was equivalent to a 46 percent intensity difference in the case illustrated. Apparently, however, only certain cells show such selective responses.

Among the problems awaiting solution in this area is the fact that those retinula cells of *Calliphora* which discriminate plane of polarization do so well with blue stimuli, but do so poorly with red stimuli.

Kring (1965) has been investigating the behavior of aphids in flight. When aphids alight, they tend to choose yellow or a mixture of colors containing yellow much more frequently than other colors. A field test showed that fewer aphids in natural flight alighted on plants growing through black or orange plastics than on plants surrounded by base soil. Aluminum was also effective in repelling winged aphids, confirming results reported last year. These findings have obvious practical implication.

The insect ocellus is a cup-shaped eye equipped with a lens and a pigment cup backing the receptors. The ocellus have never been considered as image-forming organs. They do, however, direct important behavior including (according to Harter, 1950) diurnal activity rhythms and (according to Willington, 1953) phototaxis.

The demonstration by von Frisch of the significance of polarized light in the behavior of bees was followed by work on other species. Kennedy (1964) stated that Kumbhani and Naka (1959) and Barthelme and Mandel (1960) independently succeeded in polarizing the retinal cells of dipteran eyes with microelectrodes. Bees recorded units showed polarized sensitivity; in the Barthelme and Mandel experiment, a 90° difference in plane of polarization was equivalent to a 40 percent intensity difference in the case illustrated. Apparently, however, only certain cells show such selective responses.

Among the problems awaiting solution in this area is the fact that those retinal cells of Calliphora which discriminate plane of polarization do not react with blue stimuli, but do so poorly with red stimuli. King (1965) has been investigating the behavior of aphids in flight.

When aphids fly, they tend to choose yellow or a mixture of colors containing yellow much more frequently than other colors. A field test showed that fewer aphids in natural flight alighted on plants growing through black or orange plastics than on plants surrounded by bare soil. Aphids was also effective in repelling winged aphids. Significant results reported last year. These findings have obvious practical implications.



Photoperiodic effects, first reported by Rice (1920), important as they are in their influence on age at maturity, seasonal egg production, seasonal breeding patterns in mammals, are only one area of interest in animal photophysiology. The work of Lauber and McGinnis (1965), showing development of buphthalmos (protruding eyes) in chickens exposed to continuous dim light will surely motivate others to further research in this area.

Photosensitization in mammals is incompletely understood. Cancer eye and pink eye in cattle are cases in point. Sunburn in white pigs and burned udders from snowshine in cows are others.

Reflection of light from plants and animals varies widely and may have possibilities for engineering manipulation. The dull greens of sagebrush and of warm weather grasses on the plains may have adaptive value.

Goldblith (1965) believes that both surface and penetrating radiation will find a place as a means of preserving protein foods such as meat, and penetrating radiation will be used for preservation of fish and marine products.

Goldblith estimated cost and throughput of bacon sterilization by a 1 megarad cobalt<sub>60</sub> source as 1530 pounds per hour at an operating cost of 2.8 cents per pound. The estimated throughput with an insulated core transformer, 3 Mev 3 KW source, was 5216 pounds at an operating cost of 0.4 cents.

Shea (1964) reported that the Food and Drug Administration has approved at least six petitions for radiation preservation of foods or sterilization of packaging materials.





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|--------------------|-----------------------------------------------------|-----------|
| Wheat and products | CO <sub>60</sub> - 20-50 megarad                    | 28FR9208  |
| Bacon              | CO <sub>60</sub> - 4.5-5.6 megarad                  | 28FR1465  |
| Bacon              | 5 Mev electron - 4.5-5.6 megarad                    | 28FR9526  |
| Bacon              | Ce 137 - 4.5-5.6 megarad                            | 28FR11797 |
| White potatoes     | CO <sub>60</sub> - 5-10 megarad                     | 28FR5588  |
| Package materials  | 2.2 Mev or less - 1 or less megarad<br>gamma energy | 28FR11651 |

What of radiation induced mutation? It has been redundantly demonstrated that, under appropriate conditions, both ionizing and nonionizing radiation are mutagenic. Frequency of mutation is a function of dosage. But there is indirect evidence, absence of identified mutations in the progeny of irradiated large animals, that causes me to be sceptical of the importance of radiation as a genetic tool for livestock breeders. Even in plants, the array of useful, radiation-induced genes is meager indeed.

Electrophysiology is an old yet ever new field of enormous potential for discovery. Nerve transmission is one portion of it. Vision depends on it as well as on reversible photochemically induced pigment change. Reproductive physiology, mediated by hormones, generally influenced by photoperiodic changes, has an essential nervous component. Humane slaughter has involved research on electric stunning devices on the one hand, and the electrophysiology of apprehension, pain, and fear on the other. Our ignorance in all these areas vastly exceeds our existing knowledge. Speculatively, the identification of control areas in the brain by electric stimulus and by microcoagulation by electrocautery could lead to new patterns of induced behavior, telemetry and remote control.





Environmental control offers many opportunities for participation in exciting research and development for agricultural engineers. Electric heating and cooling of houses and livestock shelters is commonplace, but often expensive. Insulation and underground shelters offer opportunities for lower cost environmental control. Broilers have been reared in West Virginia and Indiana caves by the thousands. There are problems; among them materials handling problems and dust control. Perhaps solar heating and cooling, highly reflective roofs and other structural devices will carry us much farther in economic, effective environmental control and greater use of electromagnetic energy. I have great faith and admiration for the creative, imaginative skill and knowledge of agricultural engineers in this area. I am still amazed at the USDA-California agricultural engineers who measured the cooling effect of dissipation of heat from the body of a cow on the north side of the barn to the sky.

The Hienton, Wiant and Brown dictum I give you again:

"If electrons move, there is an electric current, and consequently an electromagnetic field."

I listened to Robert Oppenheimer at the Smithsonian celebration of the 200th birthday of James Smithson in Washington on September 15. He referred to the many "particles" now commonplace, but to me still a bit confusing. "Particles"(?) by name; energy? Dr. Oppenheimer discussed a great many things; changes. No change is permanent. But perhaps only two things are permanent; energy and change.

"If electrons move, there is an electric current, and consequently an electromagnetic field."





Of time and space and mass and movement; parameters-- $3 \times 10^{10}$  cm/sec--the speed of light. The particles identified in the bubble chamber last more than 10 to 23 seconds. Agricultural engineers and the agriculturalists of tomorrow must expand their knowledge as well as their vocabulary (Chew, 1965). Leptons, pions, inclusions, antiparticles may become part of our common language. What foreseeable uses of the energy named as the more than 100 "particles" of "particle physics" can we foresee?

The breeder reactor is on the horizon. One was dedicated in Idaho Falls on September 13, 1965 (AP). Madell (1965) predicted that during the next 30 years the United States will burn as much fossil fuel as was consumed in all preceding years.

$1/20$  q (q=quintillion BTU's or  $1/2 \times 10^{18}$  BTU's) consumed in the United States annually. Total reserves of fossil fuel in world, 124 q.

$U_{235}$  (fissionable) in limited supply.

Fertile substances, e.g.,  $U_{238}$  and thorium 232 constitute 250 times as large a supply as fissionable material. In a breeder reactor, 1 fissile neutron is captured by breeder reactor fuel and produces more. With plutonium as fuel, 2.74 fission neutrons per "fast" neutron are captured. Number must exceed 2 for breeding new fuel.

Harnessing the enormous energies of fusion may eclipse the energies from fission. What is agricultural engineering, anyhow?

I asked Walter Carleton to tell me. He responded by sending me three definitions and a copy of a Presidential address to the American Society of Agricultural Engineers by our friend, Gene McKibben. Walter expressed a preference for the first of the three definitions he provided. I like it, too. It is:





"Agricultural engineering is the science and art of the utilization of materials, energy, and men as applied to the problems of agriculture, the industry it serves."

What are the energy requirements of agriculture? How much of these requirements will be met by electromagnetic energy in the future? We have seen horses and men displaced by energy transmitted by machines very rapidly over the past 40 years without substantial change of net energy input into farming. The horse as a source of energy in farming has almost disappeared in the United States, though in many developing countries horses have increased during this period. Everywhere men have left the land for the cities. In the United States six million people work about eight billion hours on farms. With their machines, McKibben (1959) estimated that they move 250 billion tons of soil each year. They harvest a half billion tons of grain, hay, silage, cotton, and other crops. A like amount of manure and litter has to be moved.

Will electromagnetic energy be used for these Herculean tasks in the future? May we suppose that when breeder reactors become commonplace hydrogen and oxygen will be made at such reactors and distributed as LP gas is now--for use in fuel cells? Use of fuel cells should help reduce the air pollution problem. Will such fuel cells be used with wheeled or crawler tractors like we now use? Just as the first automobiles were engines installed in buggy-like vehicles, even some of them with whipsockets? Or will the engineers use electromagnetic energy in other ways, perhaps setting systems of transmission through the soil itself, restructuring soil aggregates, restoring tilth, increasing permeability--truly a new kind of tillage? Or, perhaps wide use of soil heating cables may permit the continuous biological cycling of crop residues and wastes to return them to soil nutrients and humus?





Large as are the energy requirements I have recited, still larger may be the energy requirements of the future for moving water uphill from enormous reactor desalinization plants at seaside. How much will we pay for energy in the future? How much must we pay for water? At what point may chemistry, using nitrogen from the air, carbon dioxide and minerals, sulfur and phosphorus and other structural essentials make our foods from these basic materials as an alternate to agriculture?

An area of enormous potential for application of electromagnetic energy is the elimination of permafrost in subarctic areas, including our own Alaska. Surely we don't need more cropland now. But I believe we need to know how to make and maintain more of it should need arise. Clearing black surface to absorb sun's energy may be enough to keep permafrost away, but it's mighty slow and expensive to get rid of it this way. How can it be done better, cheaper, quicker?

In conclusion: Opportunities for application of electromagnetic energy are limited by cost, need, and the state of the art. Those who anticipate change are prepared for it, will have opportunities for service, achievement, and reward. The only permanence is change itself, energy.





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